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GYRO DORMANCY INVESTIGATION

R. Carson, et al

Charles Stark Draper Laboratory, Incorporated

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LIST OF SYMBOLS AND ABBREVIATIONS

A	Acceleration
Btu	British thermal unit
C	Radial clearance
ctks	Centistokes (measure of viscosity)
D	Drift (gyro)
d_m	mean diameter of annulus
°F	degrees Fahrenheit
gpm	gallons-per-minute
HSS	Hot Storage Sensitivity
IA	Input axis of gyroscope
IRIG	Inertial Rate Integrating Gyroscope
ℓ	length of annulus
OA	Output axis of gyroscope
P	Pressure
ΔP	Change in pressure
PIGA	Pendulous Integrating Gyroscopic Accelerometer
psi	pounds-per-square-inch
Q	Heat transfer rate
s	second
SA	spin axis of gyroscope
SDOF	Single-degree-of-freedom (gyro)
T	Temperature
ΔT	Change in temperature
σ	standard deviation
μ_m	mean absolute viscosity

SECTION 1
INTRODUCTION

This report describes tests that attempt to characterize single-degree-of-freedom (SDOF) floated inertial gyros to be used in dormant applications. The purpose of these procedures is twofold. First they provide a means of evaluating the performance of an instrument through a given dormancy environment. Secondly, data is available from which gyro modeling and analysis can be performed to identify and determine the significance of specific error-producing mechanisms. The basic approach is to monitor the instrument's response to forced temperature changes for various storage positions and over a wide temperature range from flotation. This is accomplished by determining the instrument's characteristics in three distinct dormancy environments:

a. Static behavior at five temperatues: flotation, flotation $\pm 5°$ F and flotation $\pm 10°$F.

b. Dynamic behavior from off-flotation temperatures of $\pm 5°$F and $\pm 10°$F to flotation.

c. Static behavior at flotation after being dormant at storage temperatures off flotation by $\pm 5°$F and $\pm 10°$F.

The operational range of the temperature control system was considered when the storage temperatures were selected. If a particular system thermal scenario is defined, this test plan should be modified accordingly.

A floated SDOF gyro employed in dormant application is subject to error torques from several sources. Some examples of mechanisms that produce error torques are as follows:

a. Viscous drag on the float as the fluid convects in a circular path under the combined action of a thermal gradient and gravitational field. [1]

b. Thermally induced strain on the float which causes the center of bouyancy and the center of gravity of the float to undergo a relative displacement. [1]

c. Float motions relative to the case when the float is not perfectly centered. [2]

d. Float position sensitive torques which are a result of elastic restraint, flex lead torques, and torquer scale-factor nonlinearities. The latter is of most concern when the instrument is used in a torque-to-balance mode (e.g., strapdown applications).

There are three major sections to this report. Section 3 details proposed test procedures. Section 4 presents limited test data to verify the feasibility of this test plan. The conclusions and recommendations are summarized in Section 2. Appendix A describes the thermal fluid controller which is considered essential if meaningful results are to be obtained.

1., 2. See References at end of report.

SECTION 2

SCOPE OF THE EFFORT

The original effort (as stated in task 4.2.4.3) regarding dormancy testing only called for the development of test procedures. However, previous work on the SIGHT program laid the foundation for progressing further than just developing test procedures. In fact, what happened was that not only were the procedures developed, but also they were checked out in actual tests. The work accomplished, therefore, was more than required by the SOW. Since the whole area of dormant inertial components is relatively uncharted, this task provided much additional insight into the total problem. A full definition of dormancy would have been beyond the scope of the effort; as used here, it denotes an inertial component being unpowered at a quasi-static, unfloated, thermal initial condition. Subsequently, the instrument is brought to its (normal) floated and fully-powered state. The whole objective to dormancy testing is to gain confidence that an inertial component could be used before reaching a fully stabilized state.

This document describes a method for evaluating a SDOF floated gyro used in a dormant application. It is believed to provide a good insight into the dormancy problem without requiring extremely long test periods and the digestion of volumes of data. The use of an isothermal bath (or other mechanism) to isolate instrument and environmentally-induced errors is considered to be essential. However, in order to obtain a more complete understanding of the dormancy problem, the following items would also have to be investigated.

1. Perform the complete series of tests along the intercardinal axes to determine whether or not multiple axis dormancy responses can be predicted from on-axis storage dormancy.

2. Pressure sensitivity tests should be performed to measure any torque contribution due to pressure changes of the fluid surrounding the gyro.

3. If these dormancy considerations are to be used in a strapdown application, torquer scale factor sensitivity to storage should be measured with higher resolution. This requires the use of a precision rate table.

4. The test plan could be modified to store the gyro for longer periods. If such effects as fluid stratification are of interest, then this is part of a more general problem called hot storage sensitivity (HSS). HSS is being worked as a general inertial component activity and was not properly a part of this effort.

5. Perform dormancy tests at different temperature profiles to determine whether there are any significant dynamic errors.

6. Perform tests with the gyro wheel off to determine the significance of wheel power as an error source.

SECTION 3
TEST PROCEDURES

The following test procedures are designed to characterize a SDOF floated inertial gyro for dormant applications.

3.1 Test Philosophy

Because of the many sources of torque affecting the gyro (temperature gradients, storage positions, warm-up and cool-down rates), it is believed that an isothermal bath is the best vehicle in which to conduct the tests. This is because an instrument fixture with heater control will degrade results in two areas: fixture warm-up dynamics and varying fixture-to-instrument gradients for different warm-up temperatures. Also, with the gyro mounted on a conventional fixture, cool-downs will be difficult, if not impossible to simulate at projected rates due to present temperature control methods and present fixture thermal mass.

By using the isothermal bath, these problems are minimized. Thermal gradients across the instrument are negligible since the temperature of the fluid surrounding the gyro is uniform. Controlled gyro cool-down rates of 0.7°F per minute are preferred to uncontrolled and slower flange cool-down.

Thermo-electric cooling was considered, but it was found that the thermal gradient changes between the gyro and the mounting surface or the outside air would corrupt the test objective of analyzing the torques related to the gyro independent of the mounting arrangements. If a particular system is considered, the gyro mounting scheme should be duplicated and then thermo-electric cooling might be useful.

Prior to starting a run, the instrument is stored with one of its major axes vertical for at least 4 hours to allow adequate settling.* Storage is at $\pm 10°F$ from flotation, $\pm 5°F$ from flotation, and at flotation temperature. To separate the effects of fluid gradients from other error sources, two types of turn-on are performed. The first maintains the bath at a constant temperature during instrument turn-on and the second keeps the fluid temperature equal to the instrument's temperature during turn-on. Fluid temperature change rates are +1°F per minute and -0.7°F per minute.

During turn-on and fluid temperature changes, float velocity, float position, torque and temperature are monitored. A six position calibration and a torquer scale factor check are performed after constant temperature turn-on and after one hour for a post turn-on settled value. This sequence is repeated for all other storage positions and/or temperature changes.

3.2 Data Acquisition and Reduction

The test plan requires 30 days to accumulate the data but test time may be reduced by modifying the outline as follows:

a. Limiting storage from 6 positions to as few as two positions, OA vertical and SA vertical. This assumption is made because of float/case symmetry; the same mechanisms along SA, and IA vertical storages should cause similar dormancy responses. Results from one complete test are needed to verify this assumption. The total test time required for 2 positions is reduced to ten days.

*This program deliberately ignored HSS effects for the reasons stated in Section 2. It addresses thermal transients rather than fluid stratification.

b. Narrow the temperature range limits.
Knowing the system thermal scenario reduces temperature conditions on storage. If the temperature is defined, the test can be performed and repeated in less than five days.

The following information channels must be monitored:

a. All radial and axial float position signals (five)
b. Torque signal from the closed loop servo system (digital or analog)
c. Gyro wheel current
d. Fluid temperature

Eight recording channels are necessary (one digital if the gyro torque monitor is in digital form). It is recommended that an automatic magnetic tape data acquisition system be employed to reduce the volume of data to be handled as well as facilitate direct computer data reduction. Such a system would permit existing algorithms to be utilized to correlate the following:

a. Torque and float velocity,
b. Torque and float position,
c Torque and temperature.

3.3 Test Outline

In order to properly calibrate and store the gyro, a two-axis index head should be used. One axis should permit rotation about azimuth for calibration purposes. ..ne trunion axis would require rotations of $\pm 90°$ from the vertical. The test sequence consists of:

1. Running a four position OA-vertical torquer scale-factor calibration, (IA north, south, east, west) at flotation temperature.

2. Running a six-position calibration at floatation temperature and determining reference values for unbalances and bias. The six positions are:

   a. OA up and OA down, separate D_F and D_O torques.

   b. IA up and IA down, separate D_F and D_I torques.

   c. SA up and SA down, separate D_F and D_S torques.

   The parametric values can be calculated per Table 3-1.

3. Store the gyro in the OA vertical orientati-- with all excitations off for at least four ..rs with the isothermal bath at -10°F from flotation temperature.

4. Turn the gyro on and monitor float position (radial and axial), OA rebalance torque, temperature, and wheel power for at least one hour. This data shows the torque as a function of float position change only.

TABLE 3-1

TEST POSITIONS TO DETERMINE TORQUER SCALE FACTOR, UNBALANCES AND BIAS AT CALIBRATION POINTS		
Test Position	Torque Equation	Terms Extracted
OA up OA down	D_F+D_O D_F-D_O	D_F, D_O
IA up IA down	D_F+D_I D_F-D_I	D_F, D_I
SA up SA down	D_F+D_S D_F-D_S	D_F, D_S
OA vertical with IA (N,S,E,W)	D_F+D_O+ earth rate	Scale Factor

NOTE: First order gyro model employed:

$$\omega_{IND} = D_F + D_I A_I + D_S A_S + D_O A_O + SF \omega_{act}$$

where

ω_{IND} = indicated rate

ω_{act} = actual rate

SF = scale factor

D_F = Acceleration insensitive drift term

D_I = Drift term proportional to the acceleration along the input axis

D_S = Drift term proportional to the acceleration along the spin axis

D_O = Drift term proportional to the acceleration along the output axis

5. Run a calibration similar to steps 1 and 2 at this temperature. With this data and reference values, static temperature sensitivity parameters can be determined (bias, unbalances, torquer scale factor).

6. Shut down unit for at least two hours in same position (OA vertical up).

7. Repeat steps 3 and 4 using the isothermal fluid bath to warm the unit to flotation temperature. The data shows torque as a function of float position change and unit temperature change. Also, comparing the calibrations to reference values indicates parameter repeatability after a storage condition.

8. Repeat steps 3 through 7 for OA vertical down, IA vertical up and down and SA vertical up and down storage positions.

9. Repeat steps 3 through 8 for storage temperature of -5°from flotation and flotation.

10. Repeat steps 3 through 8 for storage temperature of +10°F, +5°F from flotation and at flotation. The bath during these tests is used to cool the unit from storage conditions.

SECTION 4

TRIAL TEST RESULTS

The purpose of the trial test was directed toward validating the test procedure. With a thermal fluid fixture and instrument available to initiate this test, a limited series of dormancy tests was performed.

These tests consisted of determining the following in various instrument orientations (namely OA up, OA down, SA down, and IA down).

a. Static behavior both at flotation and off flotation temperature of -15°F* and ±10°F.*

b. Dynamic behavior from off-flotation conditions to flotation by -15°F and ±10°F temperature changes.

c. Static behavior at flotation after being dormant at some storage temperature (-15°F and ±10°F from flotation).

The results are included to verify the feasibility of this test plan using a low thermal gradient fluid controller, not necessarily to demonstrate the performance levels of the instrument, electronics, or fluid controller as individual hardware pieces. Each had recognized problems and limitations prior to testing. Specific problem areas that limited the quantitative results were:

*These temperature ranges were choosen to verify the full dynamic range of the isothermal bath. They bracket the range called out in Section 1.

1. The instrument had flex lead problems which directly affected instrument acceleration bias and indirectly affected all parameters measured.

2. The performance of the electronics seemed to be consistent with the job requirements. However, they had not been quantitatively checked out on a reference instrument in actual test modes. Therefore, their repeatibility is not totally known.

3. The fluid controller was not fully automatic as noted in Section 5. Manual control capability was designed-in to give maximum flexibility; however, this led to some minor operational inconvenience.

4. The data handling techniques used were not the most efficient and generally provided lower resolution than other available methods. This method (Sanborn Strip Chart Recorder) was the only one available at the time of testing. As mentioned in Section 1, it would be desirable to obtain the data in a computer-compatible form so that cross-correlation analysis could be applied and filtering could be used to reduce data uncertainty. These limitations must be eliminated if quantitative results for a particular instrument are required from future tests.

4.1 Summary of Results

The test data obtained demonstrated the feasibility of this test procedure as means of evaluating the performance of a SDOF gyroscope in a given environment, as well as providing information from which gyro modeling and analysis can be performed. The limited results obtained from a single 13 IRIG are encouraging and summarized below:

1 The parameter measurement and repeatability across turn-ons and storages (Table 4-1) appear to be consistent. This suggests that the instrument does not behave in an erratic manner within 15°F from flotation.

2. The instrument's temperature sensitivities measured with the fluid controller are significantly lower than previously measured in a conventional fixture-heater set up. Table 4-2 lists the temperature sensitivites obtained with and without the thermal controller.

3. There appears to be a strong correlation between the torque about the OA and the temperature of the fluid surrounding the instrument. This effect can be seen from Figures 4-1 and 4-2 which are typical responses for axial (along OA) and radial (along SA or IA) storage positions, respectively. Determining the significance of torque producing mechanisms such as 1) viscous shear, 2) thermal strain, 3) float position and 4) float velocity, would require better data resolution and cross-correlation analysis. However it is evident from these plots that the data can be obtained.

TABLE 4-1

COMPARISON OF MEANS AND 1σ ABOUT MEAN FOR STEADY STATE TORQUES UNDER STORAGE CONDITION AND 1 HOUR AFTER RETURN TO FLOTATION TEMPERATURE

		-15°F STORAGE		-10°F STORAGE		+10°F STORAGE	
		OFF FLOTATION	AT FLOTATION	OFF FLOTATION	AT FLOTATION	OFF FLOTATION	AT FLOTATION
NO. OF MEASUREMENTS		10	7	5	5	5	5
D_F	MEAN	-35.0	-45.9	-38.1	-44.1	-35.6	-41.2
meru	σ	24.7	27.9	30.8	23.0	25.7	19.3
D_S	MEAN	+62.0	-179.3	-20.6	-187.9	-262.3	-171.2
$\frac{meru}{g}$	σ	18.8	26.0	22.1	29.1	21.6	24.3
D_I	MEAN	+949.5	+1188.7	+1046.3	+1222.3	+1264.0	+1180.6
$\frac{meru}{g}$	σ	36.4	87.4	44.0	33.2	29.1	32.0
D_O	MEAN	-54.8	-71 3	-52 2	-58.0	-57.8	-58.3
$\frac{meru}{g}$	σ	15.3	19.3	34.8	17.7	17 0	13 5

1 MERU = 015 deg/hr

TABLE 4-2

COMPARISON OF TEMPERATURE SENSITIVITIES USING CONVENTIONAL FIXTURE FLANGE CONTROL AND WRAP AROUND HEATER/SENSOR TO FLUID BATH TEMPERATURE CONTROL

	1972 Servo TEMPERATURE SENSITIVITY*	ANALOG FLUID CONTROLLER TEMPERATURE SENSITIVTY			
		-15°F TO FLOTATION	-10°F TO FLOTATION	+10°F TO FLOTATION	MEAN/σ
D_F (MERU/°F)	-6.8	-0.7	-0.6	-0.6	-0.6/0.1
D_S (MERU/G/°F)	-23	-13.3	-16.7	-9.1	-13.0/3.8
D_I (MERU/G/°F)	+26	+16.0	+17.6	+8.3	+14.0/5.0
D_O (MERU/G/°F)		-1.1	-0.6	-0.1	-0.6/0.5

*MEASURED BY CHANGING UNIT TEMPERATURE ONLY ±5°F FROM FLOTATION

1 Meru = 0.0.5 deg/hr.

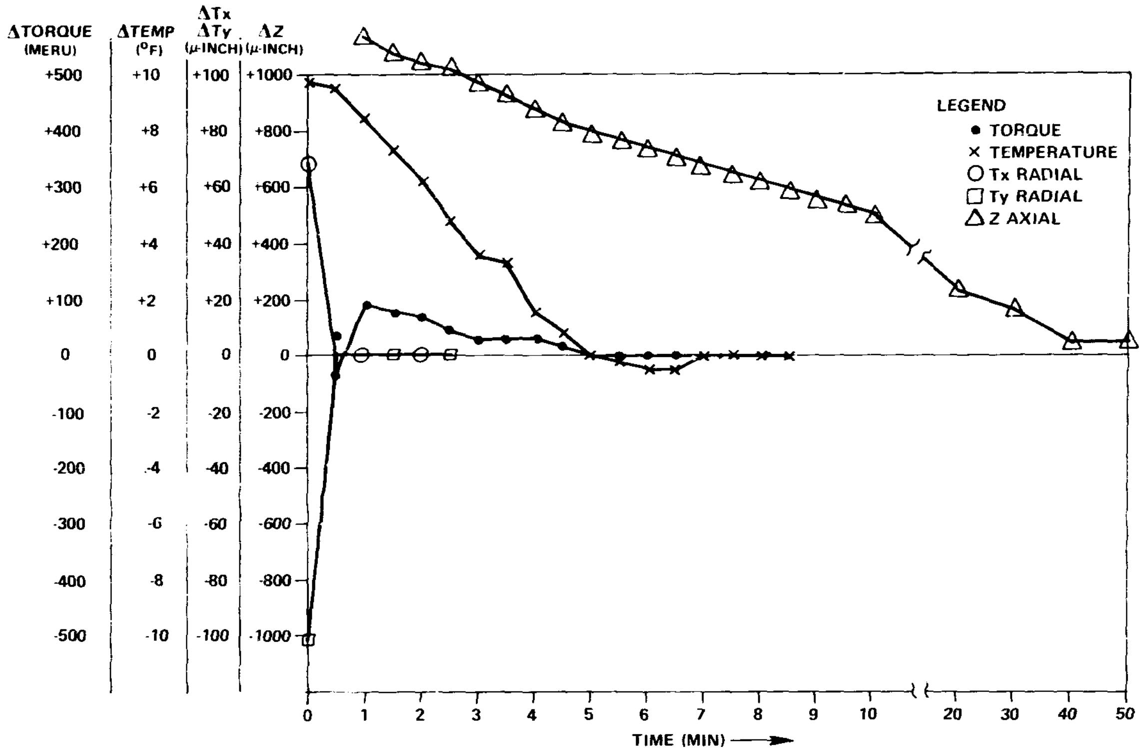


Figure 4-1. Typical Response for Axial (along OA) Storage Position from +10°F to Flotation

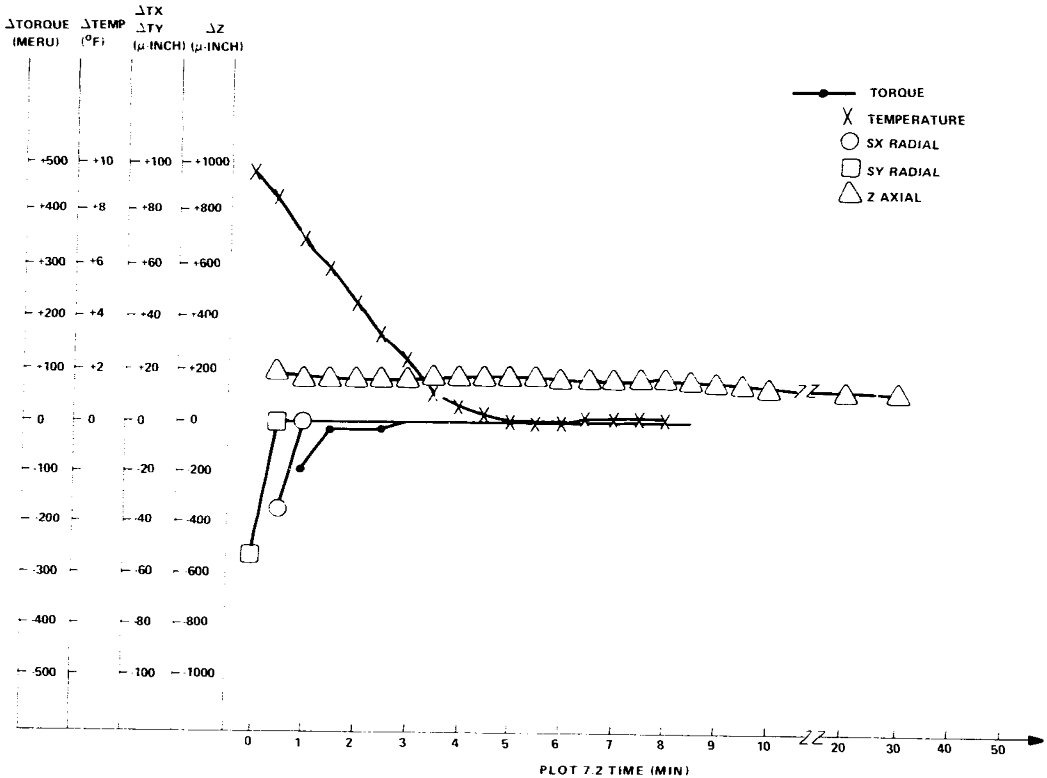


Figure 4-2. Typical Response for Radial (along SA or IA) Storage Position from +10°F to Flotation

4.2 Conclusions and Recommendations Based on Limited Trial Runs

Based on the experience obtained in the trial test runs the following conclusions and recommendations are made:

1 The controller should be changed to allow variable thermal rate control. This would allow better isolation of torque vs. float position (or velocity) from torque vs. temperature.

2. Since the present fluid controller has no volumetric compensator, the different set temperatures and thermal transients caused different case pressures on the instrument. Test should be performed to insure that responses observed are due to desired thermal inputs and not the corresponding case pressure.

3. Additional efforts to model the projected torque levels during transients might show that useful results can be realized at a degraded performance level.

4. An efficient means by which data can be recorded and preserved in a permanent form for later analysis is necessary.

APPENDIX A
THERMAL TEST FIXTURE

This fixture was designed to show that an inertial instrument placed in a thermally-controlled fluid environment would exhibit substantially reduced errors which had heretofore been attributed to thermal gradients within the instrument. To demonstrate this effect, a fixture was designed and built to provide this fluid environment. The necessary power sources and monitoring instrumentation were also built.

A 1 Design Philosophy

Figure A-1 shows schematically the basic elements of the fixture with the instrument, its housing, and a forced convection thermoelectric cooling unit. There are two separate and independent fluid loops both of which are completely filled with FC 77, and separated by a thin nickel plate. Both fluid loops can be filled with any type of fluid; the only limitation is that the fluid be a dielectric, since the instrument electrical terminations are made in the fluid. FC 77 was chosen here since it is an inert, high-density dielectric fluid which has general usage in floated systems. The instrument fluid loop pumps fluid into the gyro housing past the gyro as depicted in Figure A-2 and then recirculates it through the pump. Flow conditions within this loop are arbitrarily set prior to any given test since the pump chosen is a variable output device. The power into this loop, in the form of pumping power and electrical power to the gyro, is conducted out of the loop across the thin nickel plate and into the fluid of the circulator loop, shown to the left of the nickel plate in Figure A-1. The fluid is pumped and recirculated by the fluid circulator. The function of the forced convection thermoelectric cooling unit is to remove the heat conducted across the nickel plate into the circulator loop. The rate of heat transfer depends

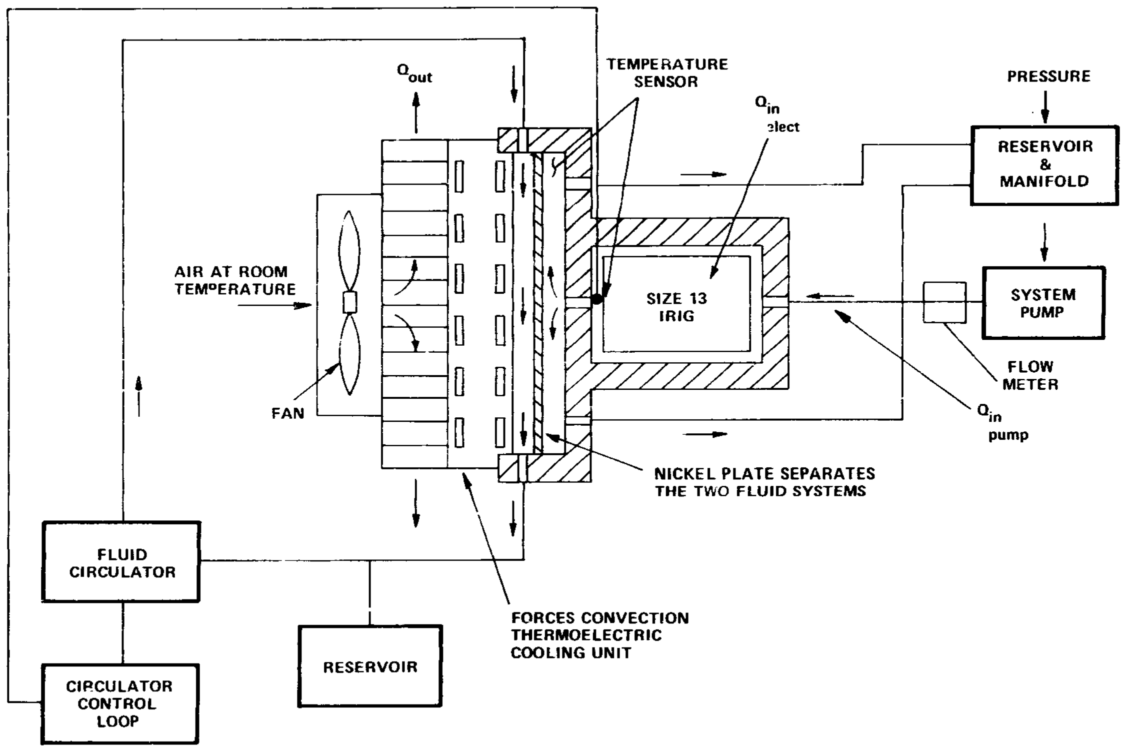
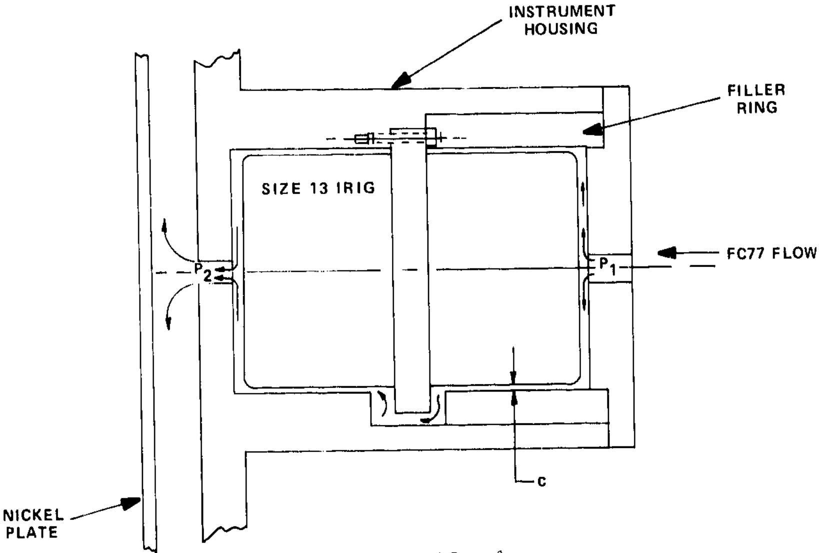


Figure A-1. 13 IRIG Thermal Test Fixture, Schematic Diagram



$$\Delta P \text{ ACROSS GYRO} = \frac{12\,Q\,\mu_m\,\ell}{C^3\,d_m\,\pi} \quad \text{(NEGLECTING EFFECT OF FLANGE ON FLOW)}$$

WHERE

P_1, P_2 = PRESSURE

ℓ = LENGTH OF ANNULUS

d_m = MEAN DIA OF ANNULUS

C = RADIAL CLEARANCE

ΔP = $P_1 - P_2$

μ_m = MEAN ABSOLUTE VISCOSITY

Q = HEAT TRANSFER RATE

Figure A-2. 13 IRIG Thermal Test Fixture Gyro Housing

on the velocity of the fluid in the circulator loop which washes across the nickel plate and the cold surface of the TE unit This method is known as the variable impedance, thermal control method. The fluid velocity in the annulus is controlled by a bridge circuit having a thermistor as one of its legs and after amplification its output drives the circulator.

A.2 Mechanization

A. General

The elements of this fixture were chosen on the basis of fabricating a device which would be thermally independent and capable of gyro test table mounting and would have no coolant lines running to or from the table. Electrical power is normally run to the table through slip rings so this poses no problem.

The available space on the turntable was limited to 13-inches in diameter by the electronics assemblies mounted on the table. The fixture weight was limited by the table bearing stiffness. Figures A-3 and A-4 show the Size 13 instrument outline and housing. This instrument was chosen on the basis of availability but the fixture is not limited to this size instrument.

Figure A-5 shows the fixture assembled.

B. Hydraulic Components

The system pump chosen is a Micro-Pump Mod #10-00-316 which is continuously variable and capable of pumping 0.8 gpm across the fixture. The pump is a centrifugal type driven by a universal AC-motor and features a magnetic drive thereby eliminating shaft seals.

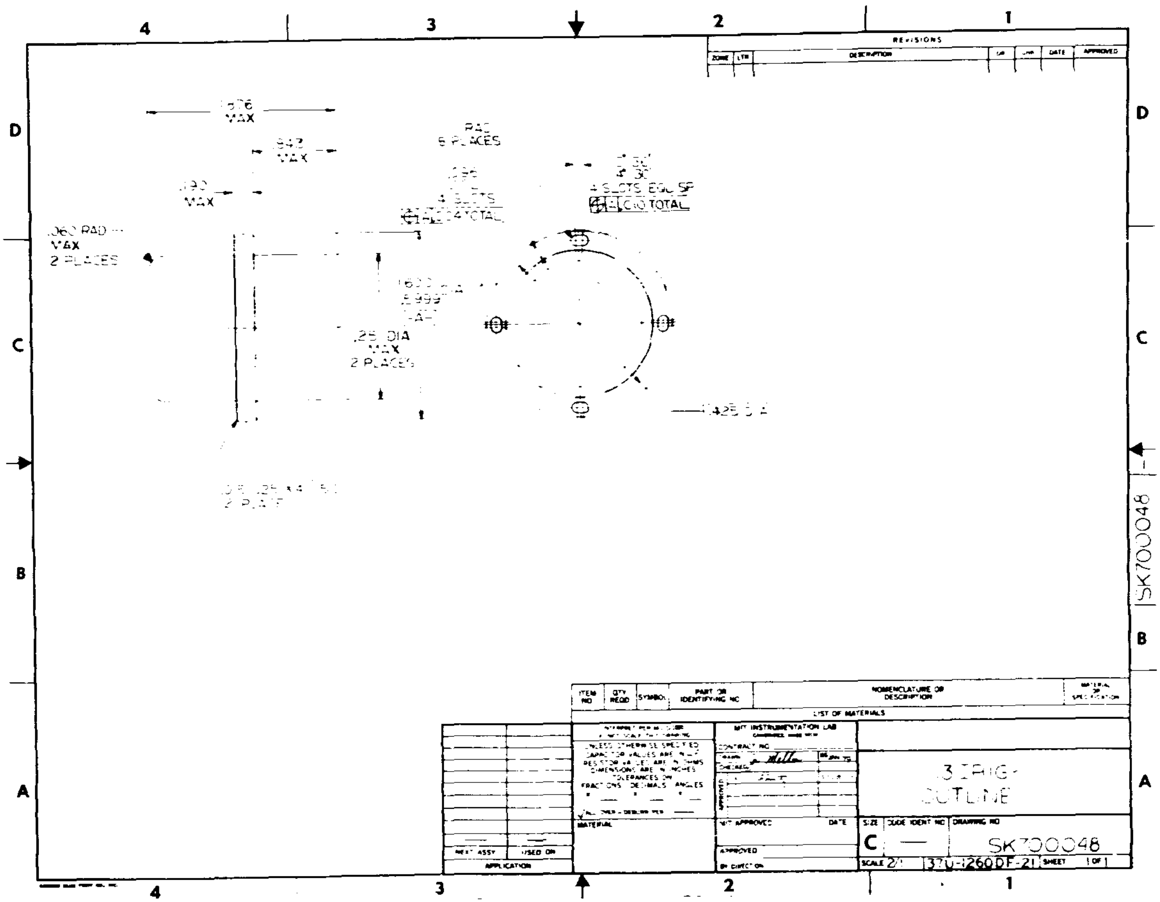


Figure A-3. Size 13 IRIG Instrument Outline - SK 700048

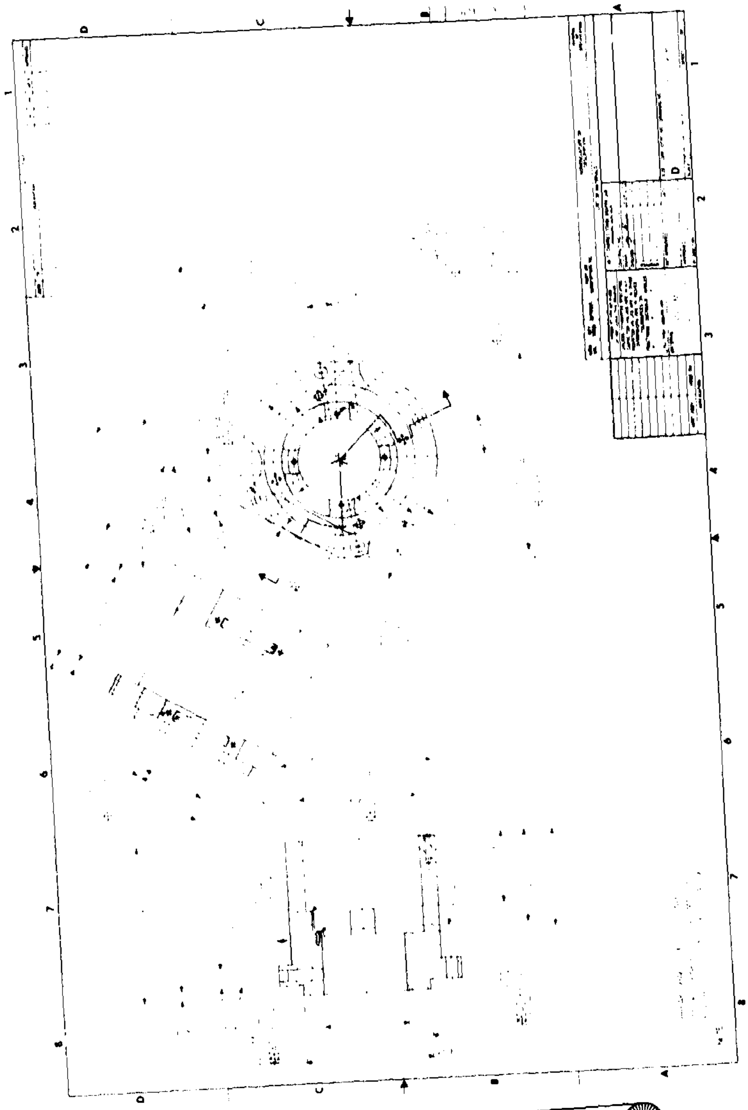


Figure A-4. 13 IRIG Thermal Test Fixture Gyro Housing Drawing-190768

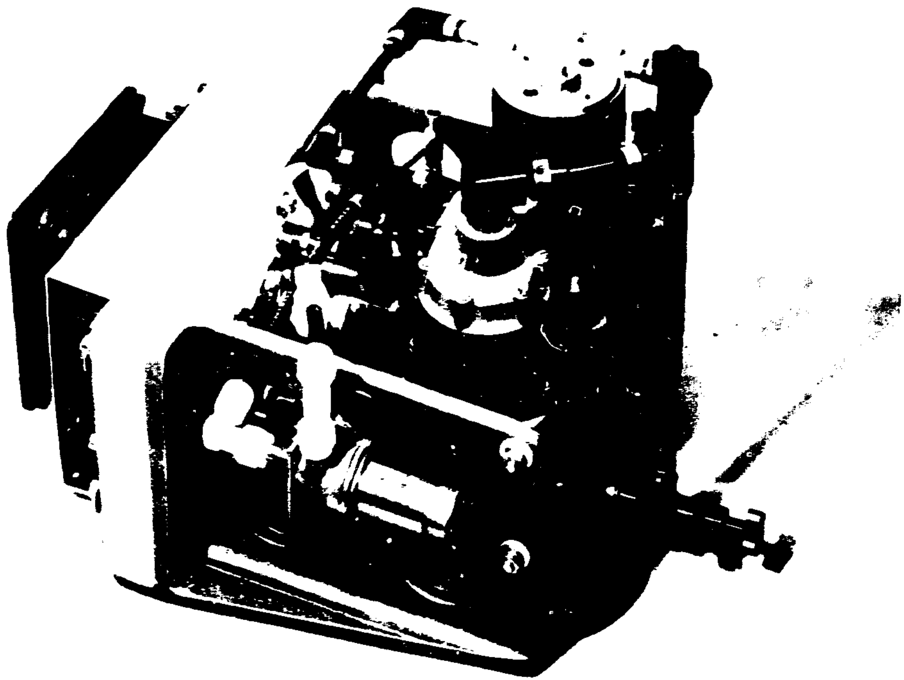


Figure A-5. Thermal Test Fixture Assembled

A Parker 10-cubic inch accumulator is used as a reservoir and for pressurizing the entire fixture. For different tests, the system ambient pressure can be varied using the accumulator. The fixture is also filled using the accumulator piston with a vacuum source to draw fluid into the fixture.

The circulator chosen was a Globe Industries/TRW model 164A158 miniature centrifugal pump, with a maximum power input of 5 watts capable of pumping 0.10 gpm at 2.5 psi. This pump features a no-leaking type of magnetic coupling between the pump and motor.

C. Electrical Components

The major electrical component of the fixture is the Forced Convection Thermoelectric Cooling Unit (TE unit) manufactured by Cambion (model #803-1066-01). This unit is used to remove the heat from the fluid of the circulator loop. The rate of removal, dependent on the velocity of the fluid passing over the cold plate, is therefore dependent on the instrument loop fluid temperature sensed by a control thermistor.

This unit, which incorporates six Cambion #3958 electric modules, utilizes the Peltier effect to achieve cooling. Sometimes this principle is also known as the reverse thermocouple effect, where a current passed through the junction of two dissimilar metals produces a cooling effect.

The cooling capacity of this assembly is 120 watts or 400 Btu/hr. and is more than adequate for the heat load of this fixture. A 10 amp DC power source is required to drive this TE unit.

A heater has been added to the fixture to provide some rapid warm-up capability and is not shown in Figure A-5 but it has been wrapped around the suction line to the pump. The output of the heater is 400 watts at 110 Vac, and is controlled manually by a Variac to whatever wattage is required for a particular test. Figure A-6 is a schematic of the circuit used to control the instrument fluid temperature. Resistance values in the variable leg of the bridge correspond to different set points of the control thermistor and each switch position represents a spread of 5°F.

D. Instrumentation

The thermistors used to both control and monitor temperatures are YSI #44014 and Figure A-7 shows the temperature resistance curve for this thermistor. There are six used, in the fixture, two being redundant. Two are used at the control point - - one to control and one to monitor - - and there is one upstream of the gyro housing and one downstream. The monitoring thermistors can be connected directly to DVM's to read out resistance, which can be converted to temperature.

Flow conditions established for any given tests must be monitored and a Cox LF6-2 flowmeter has been used. This meter produces a signal directly proportional to flow, has a range from 0.07 to 0.7 gpm with an accuracy of $\pm 0.5\%$; it is of the turbine type which produces a calibrated and known number of pulses per gallon of flow.

Figure A-8 shows the manufacturer's calibration data. Counting these pulses can be done by any one of many ways; the simplest is by connecting to a digital counter.

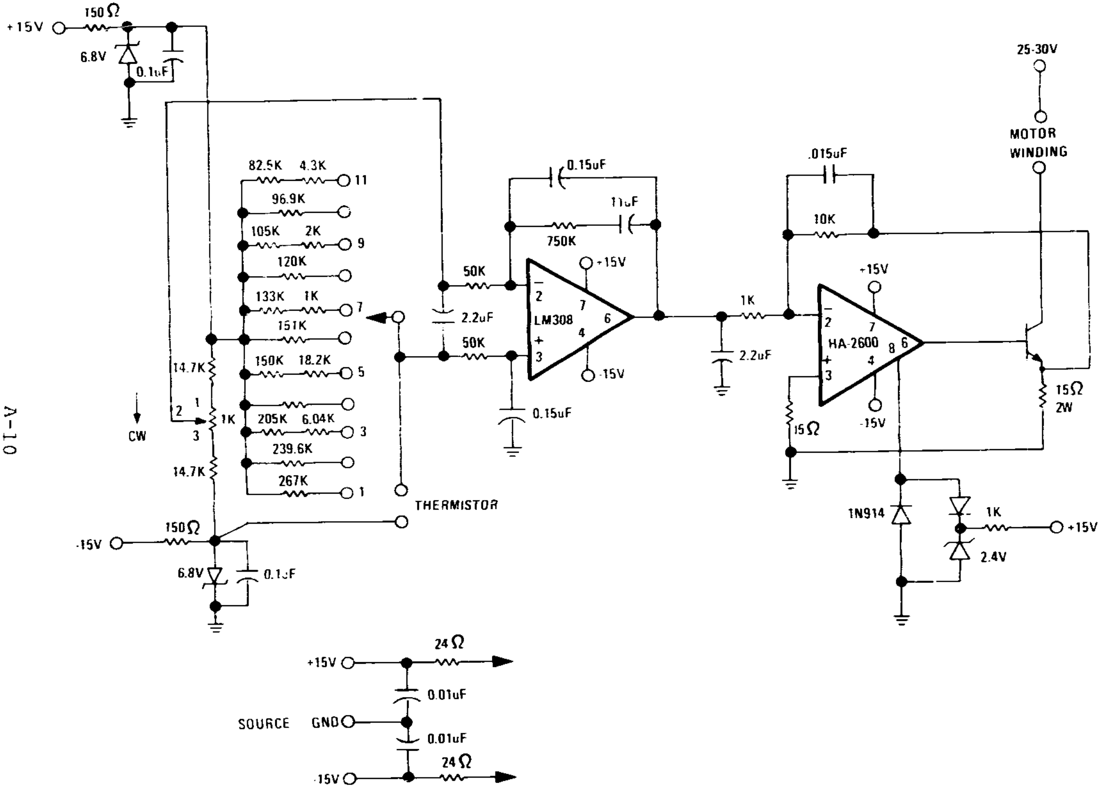


Figure A-6. Fluid Temperature Control Circuit, Schematic Diagram

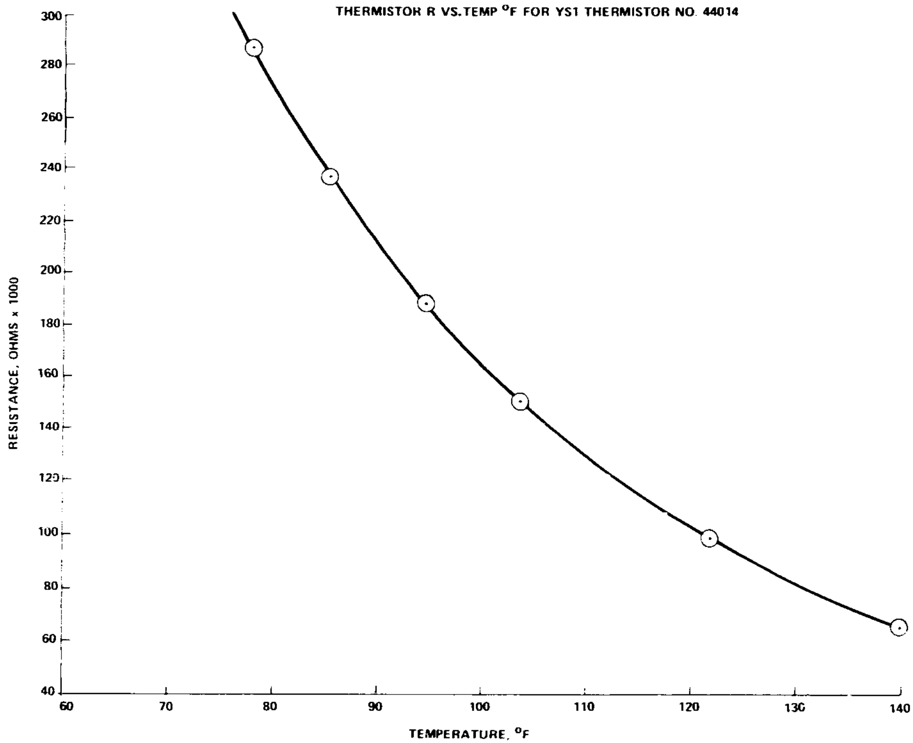


Figure A-7. Resistance vs. Temperature for YSl Thermistor No. 44014

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COX INSTRUMENT
DIVISION OF LYNCH CORPORATION
DETROIT, MICHIGAN U.S.A.

TURBINE FLOW TRANSDUCER CALIBRATION DATA

CUSTOMER CHARLES STARK DRAPER		S.O. 362043
MODEL LF 6-3	SIZE 6-3	SERIAL NO. 18594
FLUID WATER	TEMP.DEG.F. 80	S.G. = .996
PICK-OFF 82414A-1B3	CAL.STAND 11	OBSERVER KING
VISCOSITY .8656 CTKS.	RANGE .1-1 GPM	DATE MARCH 12, 1973

PSID	(MV)	CPS	(W)LB.	SEC.1	SEC.2	PPH	GPM	CYC/GAL	0/0 DEV.
		90	.3	24.55	24.56	43.983	.08838	61102.8	-9.807
	10	120	.4	25.31	25.31	56.895	.1143	62981.6	-7.034
.20		180	.6	26.28	26.25	82.239	.1652	65358.	-3.526
.40		240	.8	26.77	26.77	107.583	.2162	66614.6	-1.671
.50		300	1	27.07	27.05	133.038	.2673	67336.3	-.606
.60		360	1.2	27.12	27.10	159.351	.3202	67460.7	-.422
1.10		480	1.6	27.16	27.14	212.155	.4263	67560.2	-.275
1.60		600	2	27.15	27.15	265.193	.5329	67560.2	-.275
3.40		900	3	27.15	27.17	397.644	.799	67585.1	-.239
5 80	300	1200	4	27.22	27.23	528.926	1.0628	67746.9	0

W = POUNDS OF LIQUID IN CALIBRATION WEIGH RUN
SEC = TIME OF CALIBRATION RUN IN SECONDS

K = CYCLES/GALLON
PPH = W(2)3600/(SEC1+SEC2)
GPM = W(2)60/(SEC1+SEC2)8.328(S.G.)
NOTE: 8.328 = DENSITY OF WATER AT 60 DEG. F.
0/0 DEV = DEVIATION FROM MAXIMUM CYC/GAL.

INSPECTOR

CUSTOMER'S CONDITIONS

FUEL Water TEMP. 80^{0} F.

S.G. .996 VISC. .8656 Ctks.

Figure A-8. Flowmeter Calibration Data

This calibration was made at 80°F and some small error will be introduced by operation at 140°F. The fluid parameter that has the greatest effect on the calibration is viscosity. The change in viscosity of FC77 from 80°F to 140°F is approximately 35%. This appears to be a large number but it does not have that much influence on the calibration, since the range of values is quite low, from 0.7 ctks to 0.45 ctks. A calibration check at the upper temperature limit should be performed to minimize the flow rate error.

E. Fabrication and Assembly

Figure A-5, above, depicted the components assembled prior to covering with insulation.

Figure A-9 is a partial break-out of the assembly, with the TE unit removed. The cold plate of the TE unit is visible as is the nickel plate which separates the two fluid loops.

The white material which houses the nickel plate is machined from Mycalex Supramica 500, a material chosen for its low thermal conductivity (0.24 Btu/hr/ft^2/°F/ft). The reason for using this material is to minimize shunt heat paths to the aluminum frame and then to the table top. Supramica is exceptionally stable over a wide temperature range, is relatively easy to machine, but exceedingly difficult to fluid seal by the conventional epoxy seals used on metal-to-metal seals. It became necessary after a series of failures to make all seals of the O-ring type (both face-seals and gland-seals).

Figure A-10 shows a further breakdown, where the instrument side of the nickel plate is shown. The two sets of tubes and fittings on either side of the nickel plate are the supply and returns of the circulator side fluid. In the center of the picture is shown the instrument and housing assembly, which is further broken out in Figure A-11.

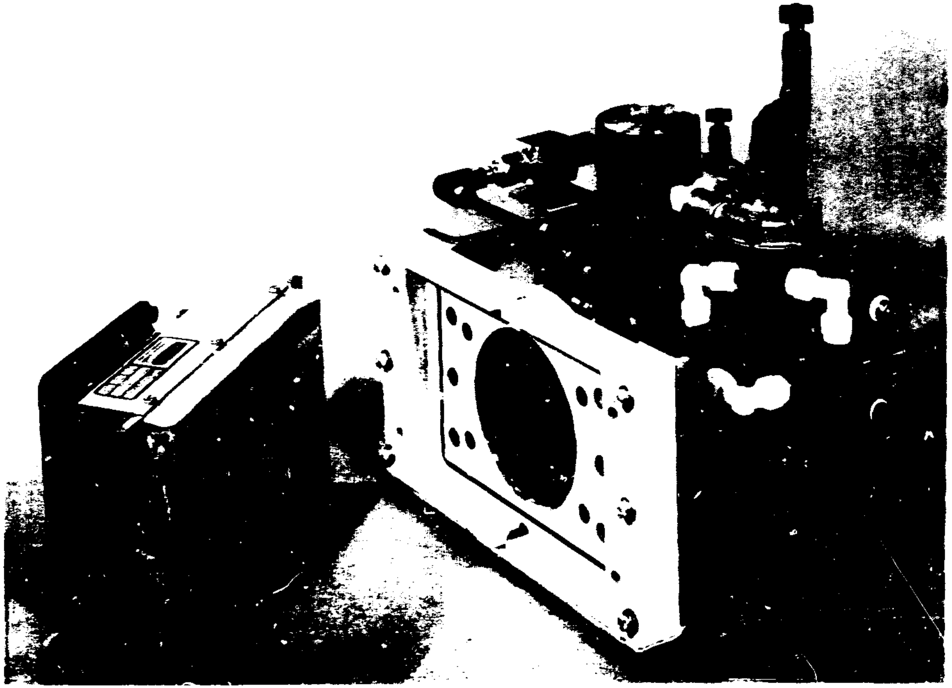

Figure A-9. Thermal Test Fixture, TE Unit Removed

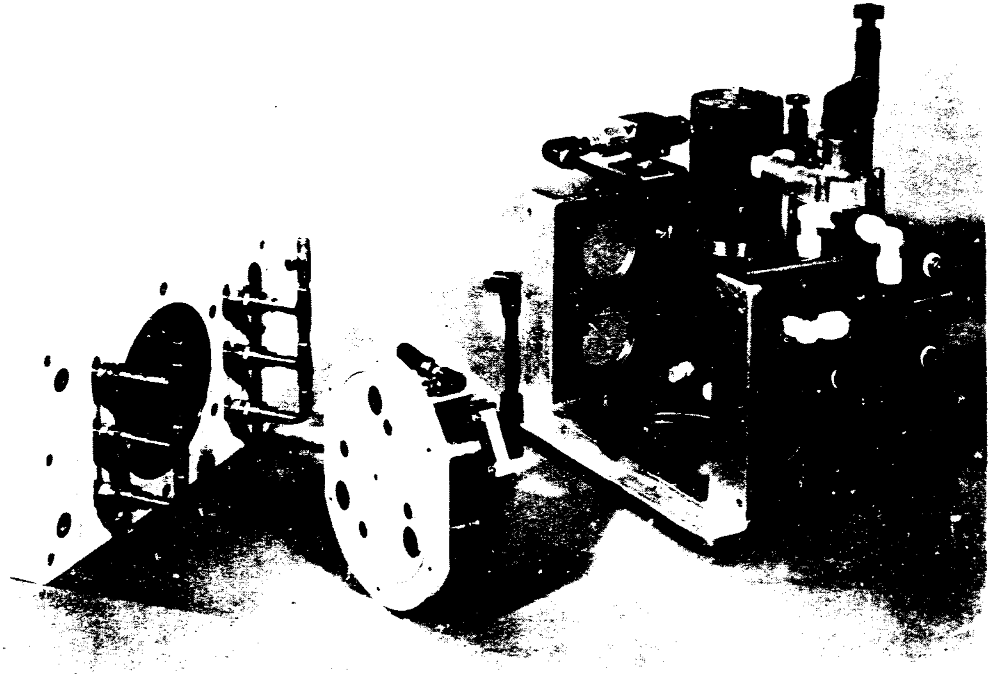

Figure A-10. Thermal Test Fixture Showing Instrument Side of Nickel Plate

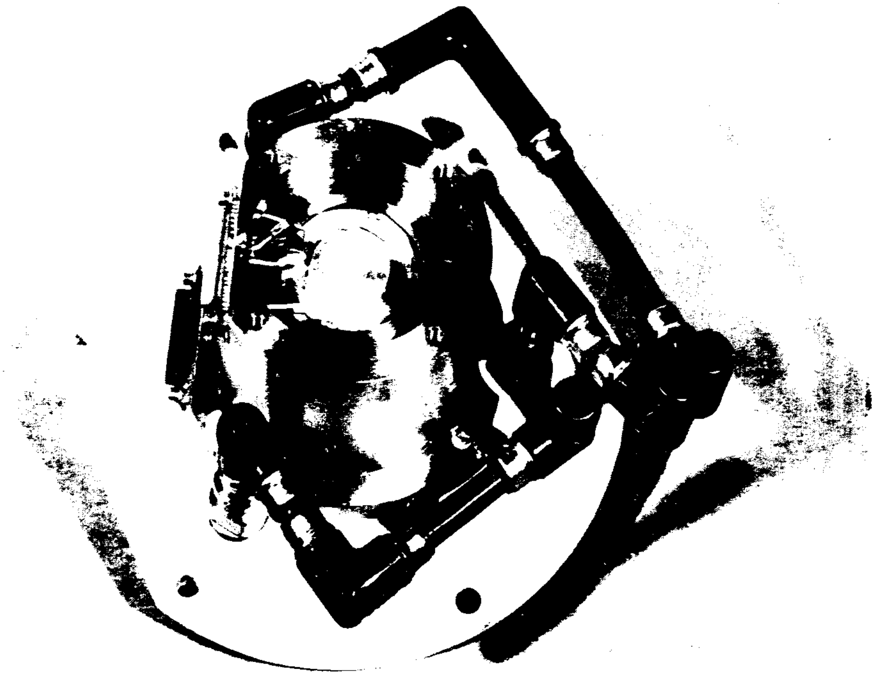

Figure 11. Test Fixture Instrument Housing

In this particular picture (Figure A-11) the instrument shown is really a dummy instrumented with thermistors and heaters. This dummy was used to verify the fixture performance prior to installing a working instrument. The metal housing for the instrument is made from Titanium 6AL-4V chosen for its low thermal conductivity. Mycalex was the first choice of material for this item, but was unavailable in the stock sizes required.

The fluid flow pattern by the instrument is not as clean as one would ideally require. The 13 IRIG as built and supplied for use in the fixture had a circumferential mounting flange midway between the two ends.

This flange presents a perturbation to the flow as shown in Figure A-2. It was necessary to duct the flow around this flange by machining out recesses in the titanium housing. A further impedance to the flow can be seen in Figure A-11 by considering that the wiring to the gyro must cross the fluid gap at both ends of the instrument.

The annular gap chosen for this first assembly was 0.020 inches. Table A-1 lists calculated values of Reynolds number, pressure drop and fluid velocities for three different gaps and flow rates.

A.3 Further Capabilities of the Fixture

The present fixture was designed for size 13 instrument. A design has been made for adaption to the size 18 instrument and it is very possible that an instrument of the 16 PIGA size could be worked into the fixture. Going smaller in size presents no problem. To adapt to different size instruments would require a new instrument housing, all other elements remaining the same. Other cooling techniques can be applied to this fixture by removing the TE unit and inserting a different

TABLE A-I

CALCULATED VALUES OF REYNOLDS NUMBER, PRESSURE DROP AND FLUID VELOCITIES FOR THREE DIFFERENT GAPS AND FLOW RATES

FLOW RATE		VELOCITY FT/SEC			REYNOLDS NO. $\frac{4R_HV}{v}$			ΔP ACROSS GYRO PSI		
GPM	$\frac{FT^3}{SEC}$	C= 0.020	C= 0.010	C= 0.005	C= 0.020	C= 0.010	C= 0.005	C= 0.020	C= 0.010	C= 0.005
1.0	$0.228X10^{-3}$	0.423	0.834	1.67	315	320	321	0.005	0.038	0.337
2.0	0.445	0.828	1.66	3.35	631	637	645	0.012	0.080	0.795
3.0	0.66	1.242	2.50	5.02	947	961	966	0.017	0.116	1.14
4.0	0.89	1.656	3.33	6.70	1263	1282	1290	0.021	0.142	1.41
5.0	1.11	2.070	4.17	8.37	1579	1602	1611	0.029	0.194	1.91
6.0	1.33	2.48	5.00	10.04	1892	1920	1933	0.035	0.234	2.31
7.0	1.55	2.89	5.83	11.72	2210	2239	2256	0.041	0.273	2.68
8.0	1.78	3.31	6.67	13.39	2527	2562	2578	0.046	0.311	3.07
9.0	2.00	3.72	7.51	15.07	2885	2901	0.052	0.351	3.46	
10.0	2.22	4.14	8.34	16.75	3159	3204	3225	0.058	0.389	3.84

type cooler. Methods of cooling that could be used are: 1) heat of fusion and 2) wicked boil-off (with nontoxic media) where heat is removed through the transformation of a solid to a liquid and a liquid to a vapor, respectively.

The fixture has been designed essentially for steady state operation. Capabilities exist, but controls do not at present, for transient tests, where gyro response can be evaluated as a function of fluid ΔT and ΔQ.

Further investigations can also be made using this fixture by varying flow patterns and velocities at the instrument to fluid interfaces. Patterns can be swirled, interrupted and broken to achieve greater heat transfer coefficients at the instrument surfaces.

REFERENCES

1. Draper, C.S., L. Trilling, and R.H. Wilkinson. Torque Induced by Convective Effects Acting on a Cylinder Floated in a Thin Layer of Viscous Fluid. Report AFAL-TR-68-71, Instrumentation Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts, August 1968.

2. Wilkinson, R.H. Float Motion Torques in a Floated Single-Degree-of-Freedom Intergrating Gyro. Report E-2488, Charles Stark Draper Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts, February 1970.